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ABOUT THE INFLOW OF GAS INTO A VARIABLE VOLUME CYLINDER

By

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About the Inflow of Gas into a Variable Volume Cylinder

(O VTEKANII GAZA V TSILINDR PEREMENNOGO OBYEMA)

by

Cand.Tech.Sc. B.V.Ovsyannikov

Article from Russian periodical Nauchniye Doklady Vysshey Shkoly,Mashinostroyeniye i Priborostroyeniye No.2,1958, pp. 68-71

This report deals in theoretical investigation of the process of gas flowing in into a vessel of variable volume.

We assume,that the air or ideal gas from the atmosphere or infinitely larger volume in the absence of an intake suction pipe line flows in through the intake organ of time variable cross section into a cylinder of varying volume (fig.1).

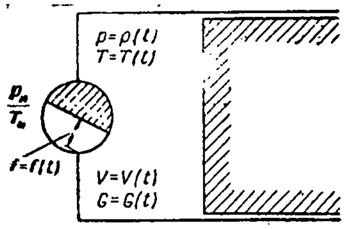

Fig.1.Schematic for calculating the inflow into a variable volume cylinder

The in-flow process is considered adiabatic. We assume that during the blending of the entered gas the velocity and thermal energy are uniformly distributed in form of thermal energy over its entire mass. In addition we assume that at the given moment all parameters of the gas can be calculated by formulas of the stablished condition,in which should be substituted the instantaneous values of all characteristic parameters,determining the state of the gas. This assumption means,that into the discussion are not introduced values,characterizing the local values and oscillatory phenomena.

On the basis of the first law of thermodynamics we will write

$$dQ_{\kappa} = dI - AVdp, \qquad (1)$$

where $dQ_k = i_n dG$ - heat brought in by the in-flowing gas during the time dt,

i_n - enthalpy of 1 kg of gas under exterior conditions, dG - amount of gas flowing in during the time dt,

dI - change in enthalpy of the gas filling up the cylinder during the time dt,

V - current volume of cylinder,

dp - change in gas pressure in the cylinder during time dt.

Equation (1) is presented in form of

$$i_к dG = d(C_p TG) - AVdp, \tag{2}$$

where C_p - specific heat of the gas,

T - current temperature value of the gas in vessel,

F - amount of gas, situated at the given moment in the vessel.

As is known:

$$C_p TG = \frac{C_p}{R} pV, \quad dG = f \frac{p_к}{\sqrt{RT_к}} \psi dt, \quad (2a)$$

where

$$\psi = \sqrt{2g \frac{k}{k-1}\left[\left(\frac{p}{p_к}\right)^{\frac{2}{k}} - \left(\frac{p}{p_к}\right)^{\frac{k+1}{k}}\right]}. \tag{3}$$

After substituting and differentiation equation (2) will acquire the form of

$$C_p \sqrt{RT_к} p_к \psi f\, dt = C_p V dp + C_p p dV - ARV dp \quad (3a)$$

We will designate

$$a = p_к \sqrt{RT_к}, \quad (3b)$$

and having divided both carts of the equation into C_v dt, we will obtain:

$$\frac{dp}{dt} + k \frac{1}{V} \frac{dV}{dt} p = ka\psi \frac{f}{V}. \tag{4}$$

In the supercritical zone, i.e. at $\frac{p_к}{p} \geqslant \left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$, (4a)

$$\psi = \psi_{max} = \left(\frac{2}{k+1}\right)^{\frac{1}{k+1}} \sqrt{\frac{2gk}{k+1}}.$$

Equation (4) at $\psi = \psi_{max}$ can be easily reintegrated, considering p as being dependent upon V = f (t) and, using the method, employed in the A.Ye.Balter (1946) experiments for solving equations conserning the outflow of gas from a variable volume cylinder.

We rewrite equation (4) in form of:

$$Vdp + kpdV = ka\psi_{max} f dt. \qquad (5)$$

The first part of equation (5) represents an absolute differential function t, provided f is a function of t only. This is not quite accurate ,because under f is necessary to understand an effective cross section, i.e. $f = \mu f'$ (μ-coefficient of narrowing the cross section, f'-geometrically transient cross section of the entry organ). f' - ordinarily depends upon the pressure drop,the effect of which is disregarded in this case.

We select the integrating multiple M = f(V),transforming the left side of equation into a total differential of a certain function t. For the existence of such multiple it is necessary that there should be equality:

$$\frac{\partial}{\partial V} M V = \frac{\partial}{\partial p} Mkp \qquad (5a)$$

Hence we will find

$$M + \frac{dM}{dV} V = Mk; \qquad (5b)$$

or

$$\frac{dV}{V} = \frac{dM}{(k-1)M}. \qquad (5c)$$

By integrating the equation, we will obtain $M = V^{k-1}$

Having multiplied equation (5) by $M = V^{k-1}$ we will obtain

$$V^k dp + kpdV \cdot V^{k-1} = V^{k-1} ka\psi_{max} f dt \qquad (5d)$$

or

$$d(V^k p) = V^{k-1} ka\psi_{max} f \cdot dt \qquad (5e)$$

Integrating within the limits of from 0 to $t \leq t_{cr}$

where 0 - initial moment of time.

t_{cr}-TIME corresponding to the establishment of critical pressure drop, we will obtain

$$Vp^k - V_0^k p_0 = ka\psi \int_0^{t<t_{kp}} \frac{f}{V^{1-k}} dt. \quad (5f)$$

Keeping in mind that $a = p_н \sqrt{RT_n}$ we will make a final conclusion:

$$\frac{p}{p_0} = \left(\frac{V_0}{V}\right)^k + \frac{kp_н \sqrt{RT_н}}{p_0} \frac{\psi_{max}}{V^k} \int_0^{t<t_{kp}} \frac{f}{V^{1-k}} dt. \quad (5)$$

According to above given formula (6), and knowing the law of change $V = f(t)$ and $f = f(t)$, it is easy to find the normally sought for dependence $p=f(t)$, i.e. the indicating diagram of ultra-critical zone. In the sub-critical zone the equation could be generally integrated. By substituting function ψ with an approximate function $\psi_1 = A\left(\frac{p}{p_н}\right) + B\left(\frac{p}{p_н}\right)$ (Balter, 1946) equation (4) can be reduced to an equation of the Bernoulli type and integrated. But as shown by investigation, the approximate function ψ_1 can satisfactorily replace the actual function ψ only to $\frac{p}{p_н} \leq 0.975$, and at the end of the inflowing process at $\frac{p}{p_н} > 0.975$ the obtained error is considerable. Practically more convenient is the way of direct numerical integration of equation (4). For this it is necessary to break down the time scale into sections Δt. For a piston engine the sections are best expressed in degrees of rotation of the crankshaft, because the magnitude of cylinder volume - V and the transient cross section of the valve - f, are ordinarily given as a function of the angle of rotation of the crankshaft α°. Assuming that ψ is constant for the length of the selected section, we calculate ψ in accordance with the drop determined for the end of the preceding section. The calculation, made by such a method is sufficiently reliable

See page 4a for Fig. 2

Fig. 2, Dependence $\frac{p}{p_н}$ upon the angle of rotation of the crankshaft.

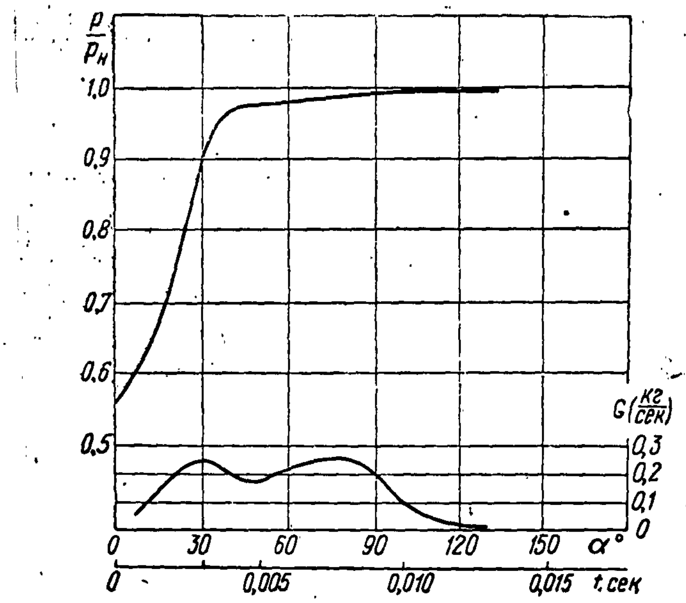
p/p_н
1,0
0,9
0,8
0,7
0,6
0,5
G(кг/сек)
0,3
0,2
0,1
0
0
30
60
90
120
150
α°
0
0,005
0,010
0,015
t, сек

Fig. 2

and does not consume much time.

Having written in equation (5) the volume constant (V=const),we will obtain formulas,introduced in 1931 by A.V.Kvasnikov.

Equation (4) can be used for the case of gas flowing in into a cylinder with freely moving piston. In this case equation (4) should be solved together with the equation describing the law of motion of a piston (law of increasing the volume) under the effect of pressure forces.

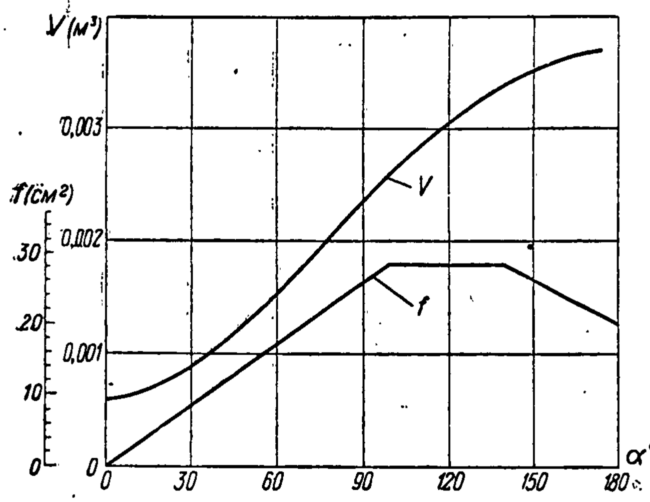

Fig.3.Dependence of cylinder volume and through section of an outlet valve upon the angle of rotation of a crankshaft.

In the role of an example fig.2.shows the dependence of the pressure ratio $\frac{p}{p_n}$ and instantaneous disbursement of the inflowing air upon the angle of rotation of engine shaft, obtained as result of calculating the process of inflowing into the cylinder of a piston engine at a given law of change in volume of the cylinder and through section of the outlet valve (fig.3).

Initial conditions:

gas pressure in cylinder p^o=1.058 kg/cm^2

pressure in the volume from which the air comes p_n = 2.000 kg/cm^2

temperature of surrounding medium T_n = 380 abs,revolutions of engine shaft n = 1660 rpm.

It is evident from fig.2 that the inflow stops practically ($\frac{p}{p_n}$=0.99) during rotation of the crankshaft from the upper dead position at a 90° turn. The increase and reduction in the consumption of inflown air is explained by the combined effect of the increase in through section of the duct and increase in the volume of the cylinder.

Conclusions

The above explained method of mathematically determining the change in pressure can be useful in practice for qualitatively investigating a number of inflow processes in piston engines. It can be applied for example, when calculating the filling of a DVS crankshaft chamber.

Literature

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